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Engineers
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August 30, 1991

PDX30702.PA.MZ

Dyke Coleman, Chairman
American Samoa Environmental Quality Commission
American Samoa Government
Pago Pago, American Samoa 96799

Subject: Supporting Documentation for the Joint Cannery Outfall Zone of Mixing Application

Dear Mr. Coleman:

Enclosed is a Technical Memorandum "*SITE-SPECIFIC ZONE OF MIXING DETERMINATION FOR THE JOINT CANNERY OUTFALL PROJECT, PAGO PAGO HARBOR, AMERICAN SAMOA*" which is intended as an attachment to the application for a zone of mixing in Pago Pago Harbor for the proposed Joint Cannery Outfall. The application was sent to you on August 8, 1991.

The main points of the overall technical approach are given in the Feasibility Study referred to in the zone of mixing application. The Technical Memorandum extends this work to a specific location. During the course of outfall design there were changes in the exact location of the diffuser, the discharge depth, the exact diffuser port dimensions, and the discharge angle which required some minor recalculations and additional model simulations to complete the Technical Memorandum and to maintain consistency between all of the project documents. We submitted the main body of the application without this Technical memorandum attachment in order to facilitate rapid review of the project.

We have been coordinating the permitting activities for this project with Sheila Wiegman of your office. A short project description was attached to the application. Detailed engineering drawings of the outfall were prepared by Makai Ocean Engineering an are provided in the Draft Environmental Impact Assessment (DEIA) prepared for this project. Copies of the DEIA were sent to your office in early August.

Copies of the application for the zone of mixing and this Technical Memorandum have been forwarded to Norman Lovelace of the USEPA. If you or your staff need any additional information please call me at your convenience. If I am not at my desk you can leave a message on my voice mail at (415) 652-8149 extension 2251.

Sincerely,

CH2M HILL

Steven L Costa

Steven L. Costa
Project Manager
Enclosure
cc: Sheila Wiegman/ASEPA
Norman Lovelace/USEPA
Pat Young/USEPA
Norman Wei/StarKist Seafood
James Cox/Van Camp Seafood

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T E C H N I C A L   M E M O R A N D U M   CH2M HILL

TO: File

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FROM: Steve Costa/CH2M HILL/SFO

DATE: August 26 1991

SUBJECT: SITE-SPECIFIC ZONE OF MIXING DETERMINATION FOR THE JOINT CANNERY OUTFALL PROJECT: PAGO PAGO HARBOR, AMERICAN SAMOA

PROJECT: PDX30702.PA.MZ

PURPOSE

StarKist Samoa and Samoa Packing Company discharge treated wastewater from tuna cannery operations into the inner part of Pago Pago Harbor. The canneries are proposing to replace the existing outfalls with a single, jointly operated, outfall extending into the outer portion of the harbor. However, a zone of mixing will be required since water quality standards can not be met at the point of discharge. The purpose of this memorandum is to provide technical documentation for the zone of mixing application for the joint cannery outfall.

The development of the technical approach and preliminary analyses were done for the *Engineering and Environmental Feasibility Evaluation of Waste Disposal Alternatives* (CH2M HILL 1991) which will be referred to as the Feasibility Study below. This technical memorandum follows the methodology developed during the Feasibility Study and addresses additional information and model results for the discharge location and diffuser configuration selected during final design. **The dimensions and location of the zone of mixing are substantially the same as described in the Feasibility Study report.**

APPROACH AND SCOPE

The approach used in developing the final configuration of the zone of mixing includes the following elements:

[1] Review and summarize the effluent characteristics of both canneries and determine the anticipated range of variation of the characteristics of concern for defining the zone of mixing.

[2] Develop and recommended final diffuser configuration based on: the preliminary analysis done for the Feasibility Study, the effluent characteristics, and the location, depth, and other constraints imposed by the final outfall design. The final outfall design was conducted by Makai Ocean Engineering, Inc. The selection of final diffuser configuration was an iterative process involving predicted diffuser performance, engineering design considerations, and environmental criteria.

[3] Predict initial dilution of the final diffuser configuration for the range of effluent and receiving water conditions anticipated.

[4] Predict the ambient concentrations of total phosphorus (TP) and total nitrogen (TN) throughout the harbor based on TN and TP loadings of the cannery effluent.

[5] Use the effluent concentrations, the initial dilution predictions for the final design, and the predicted ambient concentrations to predict the required size and geometry of the zone of mixing.

A more complete description of the approach and the models used is provided in the Feasibility Study and the Appendices to the Feasibility Study. The scope of this technical memorandum involves an extension of the modeling, analysis, and predictions done for the Feasibility Study.

EFFLUENT CHARACTERISTICS

The effluent characteristics of primary concern in defining the dimensions of the zone of mixing are the effluent flow rates, effluent density, and the concentrations and loadings of TN and TP. The establishment of a zone of mixing for TN and TP will be sufficient to provide for other water quality characteristics such as temperature. The effluent characteristics used to develop the necessary zone of mixing geometry are based on the time period after high strength waste segregation was started (August 1990). The flow, concentration, and loading data used below are representative of times of product processing.

EFFLUENT DISCHARGE RATES

Discharge rates used in the zone of mixing analysis were based on flows recorded during the twice weekly sampling conducted by the canneries. The period of record for StarKist Samoa (SKS) was from August 8, 1990 through May 13, 1991, and for Samoa Packing Co.

(SPC) from August 6, 1990 through March 27, 1991. Cumulative frequency distributions were constructed for these records and are presented in Table 1. The median flows were 1.83 million gallons per day (mgd) for SKS and 0.56 mgd for SPC. The average flows for SKS and SPC, for the period of record, were 1.78 and 0.58 mgd, respectively. The anticipated future flow maximum for SKS and SPC combined is estimated to be 4.8 mgd.

Table 1
FREQUENCY DISTRIBUTION OF EFFLUENT DISCHARGE RATES

Cumulative Frequency: Percent of Time Flow is Equal to or Less Than Tabulated Value	Effluent Discharge Rate (mgd)	
	StarKist Samoa	Samoa Packing Co.
1	1.04	0.37
5	1.27	0.44
10	1.41	0.45
25	1.63	0.51
50	1.83	0.56
75	1.95	0.64
90	2.00	0.71
95	2.10	0.76
100	2.61	0.79

= 3.4

EFFLUENT DENSITY

The difference in density between the effluent and the receiving waters is an important parameter in determining the initial dilution and the trapping level of the effluent plume. The effluent density depends on the temperature and salinity of the effluent. The temperature range of the effluent from both canneries is limited to a few degrees and does not have a large effect on effluent density. This range is between 85 and 90 degrees F.

The salinity varies due to the use of sea water by SKS. The amount of sea water used has been approximately 60 percent of the total effluent stream. Approximately 0.6 mgd of seawater is used by SKS for thawing and the remainder has been used for cooling purposes. It is anticipated that about 0.6 mgd of sea water will be used by SKS in the future.

EFFLUENT TN AND TP LOADINGS

TN and TP loadings (pounds per day) and concentrations (mg/l) used in the zone of mixing analysis were based on samples analyzed for the twice weekly sampling conducted by the canneries. The period of record for SKS data was from August 8, 1990 through March 29, 1991 and includes 64 samples. The period of record available for SPC data was from August 6, 1990 through March 27, 1991 and includes 69 samples. Cumulative frequency distributions were constructed for both TN and TP loadings and are presented in Table 2.

The median loadings for TP were 127 lbs/day for SKS and 153 lbs/day for SPC. The average TP loadings for SKS and SPC, for the period of record, were 134 and 160 lbs/day, respectively. The anticipated future maximum TP loading for SKS and SPC combined is approximately 600 lbs/day.

Table 2
FREQUENCY DISTRIBUTION OF TN AND TP LOADINGS

Cumulative Frequency: Percent of Time Loading is Equal to or Less Than Tabulated Value	TP LOADINGS (lbs/day)		TN LOADINGS (lbs/day)	
	SKS	SPC	SKS	SPC
1	40	77	445	136
5	48	103	566	306
10	55	119	683	334
25	79	130	851	411
50	127	153	1020	477
75	171	188	1228	570
90	230	208	1427	673
95	257	225	1720	772
100	312	267	1925	1052

✓ ≈ 600 ✓ 3500 - 4000

anticipated future max. loads based on what flow? 4.8 or 3.4?

The median loadings for TN were 1020 lbs/day for SKS and 477 lbs/day for SPC. The average TN loadings for SKS and SPC, for the period of record, were 1061 and 506 lbs/day, respectively. The anticipated future maximum TN loading for SKS and SPC combined is approximately 3500 to 4000 lbs/day.

EFFLUENT TN AND TP CONCENTRATIONS

TN and TP concentrations used in the zone of mixing analysis were based on the same samples and periods of record as the loadings discussed above. Cumulative frequency distributions were constructed for both TN and TP concentrations and are presented in Table 3.

The median concentrations for TP were 8 mg/l for SKS and 34 mg/l for SPC. The average TP concentrations for SKS and SPC, for the period of record, were 9 and 33 mg/l, respectively.

The median concentrations for TN were 66 mg/l for SKS and 104 mg/l for SPC. The average TN concentrations for SKS and SPC, for the period of record, were 69 and 104 mg/l, respectively.

Table 3
FREQUENCY DISTRIBUTION OF TN AND TP CONCENTRATIONS

Cumulative Frequency: Percent of Time Concentration is Equal to or Less Than Tabulated Value	TP CONCENTRATION (mg/l)		TN CONCENTRATION (mg/l)	
	SKS	SPC	SKS	SPC
1	2	17	32	28
5	3	20	35	67
10	4	23	46	77
25	6	29	55	85
50	8	34	66	104
75	11	38	79	121
90	14	42	90	140
95	16	43	114	146
100	20	48	125	183

DIFFUSER CONFIGURATION

Preliminary diffuser configuration and performance for a range of potential conditions and locations were investigated for the Feasibility Study. The results of the Feasibility Study indicated a general location for the diffuser. The final design of the outfall fixed a more precise location and other parameters such as pipe size and water depth. The selection of a final diffuser configuration was based on desired performance, design criteria for the outfall, and location in the harbor.

The important elements of the diffuser configuration include: number of ports, port diameter, port spacing, and port orientation. Each of these parameters is first discussed below in general terms. More specific and detailed development of the selected configuration follows the general discussion.

GENERAL CONSIDERATIONS

Port orientation is important for a variety of reasons but is not considered in detail for this diffuser because: [1] port spacing is set to minimize individual plume merging, [2] current directions are not well known and diffuser configuration and initial dilution predictions were generally based on the zero current, worst case, assumption, and [3] the depth of the diffuser insures trapping well below the surface. General practice for best performance is to set the ports to discharge close to horizontally, sequentially alternating sides on the diffuser pipe, and to set them normal to the diffuser axis. This was the approach used for the port arrangement.

Closely spaced ports minimize diffuser length and thus materials and construction costs. However, closely spaced ports may result in merging of individual plumes and result in lower initial dilutions than would be achieved for larger port spacings. The procedure followed below was to fix port spacing to minimize merging.

Port size and number of ports effect initial dilution primarily by controlling effluent volume flow and velocity from each port. Higher velocities and lower volumes increase, in general, initial dilution. There are practical limits on size and numbers of ports including head loss, constructibility, and maintenance considerations. Based on experience with outfalls and diffusers, there are some general ground rules that can be applied for preliminary diffuser configuration development. These general guidelines include:

- Total port area should be between 1/3 and 2/3 of the area of the outfall pipe.

- Port velocities vary from 6 to 15 feet per second.

- Densimetric Froude Numbers are generally in the range of 15 to 30, with peaks no higher than 40 to 50.

- Port diameters are usually in the range of 3 to 9 inches.

The nominal diameter of the outfall pipe is 16 inches corresponding to a cross-sectional area of approximately 201 square inches. The number of ports of a given diameter should be in the range shown in Table 4 in the columns for minimum and maximum number of ports. Table 4 also indicates the port discharge velocities corresponding to the port diameters and numbers tabulated, for a representative range of total effluent flow rates. The data presented in Table 4 are interpreted as follows:

- The total flows of 0.37 and 1.41 mgd are the minimum flows for SPC (lowest single cannery flow) and for SPC plus SKS (lowest combined flow), respectively (see Table 1). This range of flows represents low flow conditions and the generally accepted criteria is that the Densimetric Froude Number associated with the flows should remain above 1 or 2. This will be discussed further below.

- The flow rate of 3.4 mgd is the combination of the maximum flow rates for both canneries. It represents a condition of very low probability under present operational practices at the canneries. This flow should be result in a Densimetric Froude Number of less than 40 to 50 (discussed further below) and should not result in velocities of over about 20 to 25 ft/sec through the ports. The latter condition is not a constraint as indicated in Table 4.

- The flow rate of 2.39 mgd is the combined median flows for both canneries. This value is taken as the design flow for the purposes of this discussion. The shaded portions of Table 4 highlight conditions where the velocity is between 6 and 15 ft/sec. The shaded entries indicate that the entire range of port sizes considered can accommodate the design flow rate and also meet the port-to-pipe area ratio criteria.

Table 4
PORT CONFIGURATION CHARACTERISTICS

PORT DIAMETER (inches)	PORT AREA (sq.in)	NUMBER OF PORTS (minimum)	TOTAL FLOW (mgd)	PORT VELOCITY (ft/sec)	NUMBER OF PORTS (maximum)	TOTAL FLOW (mgd)	PORT VELOCITY (ft/sec)
3	7.07	9	0.37	1.30	19	0.37	0.61
			1.41	4.94		1.41	2.34
			2.39	8.37		2.39	3.97
			3.40	11.91		3.40	5.64
4	12.57	5	0.37	1.31	11	0.37	0.60
			1.41	5.00		1.41	2.27
			2.39	8.48		2.39	3.85
			3.40	12.06		3.40	5.48
5	19.63	3	0.37	1.40	7	0.37	0.60
			1.41	5.33		1.41	2.29
			2.39	9.04		2.39	3.87
			3.40	12.86		3.40	5.51
6	28.27	2	0.37	1.46	5	0.37	0.58
			1.41	5.56		1.41	2.22
			2.39	9.42		2.39	3.77
			3.40	13.40		3.40	5.36
7	38.48	2	0.37	1.07	3	0.37	0.71
			1.41	4.08		1.41	2.72
			2.39	6.92		2.39	4.61
			3.40	9.84		3.40	6.56
8	50.27	1	0.37	1.64	3	0.37	0.55
			1.41	6.25		1.41	2.08
			2.39	10.59		2.39	3.53
			3.40	15.07		3.40	5.02
9	63.62	1	0.37	1.30	2	0.37	0.65
			1.41	4.94		1.41	2.47
			2.39	8.37		2.39	4.19
			3.40	11.91		3.40	5.95
10	78.54	1	0.37	1.05	2	0.37	0.52
			1.41	4.00		1.41	2.00
			2.39	6.78		2.39	3.39
			3.40	9.65		3.40	4.82
11	95.03	1	0.37	0.87	1	0.37	0.87
			1.41	3.31		1.41	3.31
			2.39	5.60		2.39	5.60
			3.40	7.97		3.40	7.97
12	113.10	1	0.37	0.73	1	0.37	0.73
			1.41	2.78		1.41	2.78
			2.39	4.71		2.39	4.71
			3.40	6.70		3.40	6.70

- Unusually large port areas (10 to 12 inches in diameter) are included in Table 4 for comparison purposes. These large ports would be less expensive to construct, result in lower operating costs because of lower head losses, and have lower potential maintenance problems.

Densimetric Froude Numbers are given in Table 5 for extremes in receiving water conditions and for the range of effluent flow rates and densities anticipated. Densimetric Froude Number depends on receiving water density, effluent density, port diameter, and port discharge velocity. The range of ambient densities is estimated to be between 1.0227 and 1.0234 grams per cubic centimeter. The range of effluent densities is estimated between 0.9550 and 1.0011 g/cc. For these conditions, and the range of port diameters used in Table 4,the velocities associated with Froude Numbers of 2, 15, 30, and 50 were calculated and presented in Table 5. The interpretations of the results given in Table 5 are as follows:

- In outfalls with large variations in flows there is the potential for sea water intrusion at flows well below design conditions. Froude Numbers should remain above 1 or 2 (or possibly higher) to avoid sea water recirculation in the outfall. Long periods of such conditions can lead to sediment accumulation in the outfall and biofouling of the diffuser ports. To avoid this problem the velocity given in Table 5 for Fr = 2 should be equal to or lower than the velocities given for the minimum flows of Table 4. Examination of these data indicates that the use of ports larger than 9 inches in diameter may lead to problems associated with sea water intrusion.

- Maximum flows should result in a Froude Number of less than about 40 to 50. Examination of the velocities predicted for Fr = 50 in Table 5 and conditions for maximum flow rates indicates that maximum anticipated flows through the appropriate number of ports will not exceed 30 and the maximum condition is not a problem in diffuser configuration design.

- The criteria that flows should result in Froude Numbers between 15 and 30 means that velocities given in Table 4 should be above the velocities for Fr = 15 in Table 5. This condition is met for port diameters between 3 and slightly less than 6 inches as indicated by the shaded areas of table 5. In all cases the number of ports would have to be less than the maximum number listed to meet the Fr => 15 criteria.

Table 5
PORT DYNAMICS CHARACTERISTICS
Fr = Densimetric Froude Number

g' (ft/s/s)	PORT DIAMETER (inches)	PORT VELOCITY (ft/sec)			
		Fr = 2	Fr = 15	Fr = 30	Fr = 50
0.89	3	0.94	7.08	14.17	23.61
	4	1.09	8.18	16.36	27.26
	5	1.22	9.14	18.29	30.48
	6	1.34	10.02	20.03	33.39
	7	1.44	10.82	21.64	36.07
	8	1.54	11.57	23.13	38.56
	9	1.64	12.27	24.54	40.90
	10	1.72	12.93	25.87	43.11
	11	1.81	13.56	27.13	45.21
	12	1.89	14.17	28.33	47.22
0.68	3	0.82	6.18	12.36	20.60
	4	0.95	7.14	14.27	23.79
	5	1.06	7.98	15.96	26.59
	6	1.17	8.74	17.48	29.13
	7	1.26	9.44	18.88	31.47
	8	1.35	10.09	20.18	33.64
	9	1.43	10.70	21.41	35.68
	10	1.50	11.28	22.57	37.61
	11	1.58	11.83	23.67	39.45
	12	1.65	12.36	24.72	41.20

Based on general criteria derived from experience with outfall systems as reported in the engineering literature, and the desire to use the largest ports possible, the 5 to 6-inch port configurations appear to be the most desirable. Smaller ports generally result in higher initial dilutions and thus would require a smaller zone of mixing. However, using larger ports is particularly important for this case since the diffuser will be in deep water (nearly 180 feet) and the cost associated with clogged or plugged ports could be substantial. To further assist in selecting a final diffuser configuration that balances these two conflicting objectives, sensitivity studies for initial dilution performance were done as described below.

DIFFUSER PERFORMANCE SENSITIVITY

The sensitivity of diffuser performance (initial dilution and trapping depth) to environmental parameters, effluent characteristics, and diffuser configuration was investigated to aid in final diffuser configuration selection. The model UDKHDEN, which is described in more detail in the Feasibility Study, was used for the sensitivity analysis. The models UDKHDEN and UMERGE were both used for the Feasibility Study. However, UDKHDEN is considered more sensitive to changes in receiving water and effluent characteristics and was the only model used for developing the sensitivity analysis presented here.

The sensitivity analysis considers two receiving water conditions: a stronger density gradient representative of trade wind conditions and a weaker density gradient representative of non-trade wind conditions. These density gradients were developed from available data from stations close to the proposed diffuser location. The density gradients used are given in Table 6.

The analysis presented below generally considers a discharge depth of 160 feet, port sizes of between 4 to 8 inches, number of ports equivalent to about one-half the area of the outfall pipe, and effluent densities consistent with approximately 40 percent sea water. More detailed considerations of some of these factors is considered in the subsequent development of the final diffuser configuration presented after the initial sensitivity analysis.

Sensitivity to Port Spacing

Table 7 summarizes model predictions showing the sensitivity of diffuser performance to port spacing. A port spacing of 50 feet results in merging plumes at the trapping level for the stronger stratification conditions. Under weaker stratification the plumes

Table 6
RECEIVING WATER DENSITY PROFILES USED FOR
DIFFUSER CONFIGURATION SENSITIVITY ANALYSIS

DEPTH (meters)	DENSITY (sigma-t units)	
	STRONGER GRADIENT	WEAKER GRADIENT
0	23.02	22.65
3	23.02	22.65
6	23.13	22.68
9	23.13	22.68
12	23.20	22.68
15	23.28	22.68
18	23.28	22.68
21	23.28	22.68
24	23.36	22.68
27	23.36	22.68
30	23.36	22.68
33	23.36	22.68
36	23.36	22.68
39	23.36	22.68
41	23.36	22.68
44	23.36	22.68
47	23.36	22.69
49	23.43	22.71
55	23.43	22.71

merge prior to trapping but higher initial dilutions also result since the trapping level is higher in the water column. A port spacing of approximately 50 feet was chosen as resulting in the best overall performance of the diffuser configuration. Table 7 also indicates the better performance of smaller ports.

Table 7

EFFECT OF PORT SPACING ON INITIAL DILUTION

Discharge Depth = 160 ft
Effluent Flow Rate = 2.0 mgd
Effluent Temperature = 85 F
Current Velocity = 0 cm/sec

PORT SIZE (inches)	PORT NUMBER	DENSITY PROFILE	DILUTION	TRAPPING LEVEL – ft (m)	PLUME WIDTH AT TRAP. LEVEL	PLUMES MERGE
Results for Port Spacing = 25ft						
4	7	S	366	72.5 (22.1)	36 (11)	YES
4	7	W	590	12.0 (3.5)	46 (14)	YES
6	4	S	260	69.6 (21.2)	36 (11)	YES
6	4	W	432	surface	50 (15.3)	YES
8	2	S	205	45.0 (13.7)	44 (13.5)	YES
8	2	W	277	surface	47 (14.4)	YES
Results for Port Spacing = 50ft						
PORT SIZE (inches)	PORT NUMBER	DENSITY PROFILE	DILUTION	TRAPPING LEVEL – ft (m)	PLUME WIDTH AT TRAP. LEVEL	PLUMES MERGE
4	7	S	471	73.8 (22.5)	44 (13.5)	YES
4	7	W	903	14.4 (4.4)	61 (18.5)	YES
6	4	S	334	71.9 (21.9)	46 (14)	YES
6	4	W	636	11.5 (3.5)	62 (19)	YES
8	2	S	291	47.9 (14.6)	57 (17.5)	YES
8	2	W	439	surface	64 (19.6)	YES

Note: S=strong density gradient W=weak density gradient

Sensitivity to Effluent Flow Rate

A representative range of effluent flow rates is presented in Table 8 for both density gradient conditions and a range of port sizes. Port Spacing is held at 50 feet. At the higher flow rates initial dilution decreases and plume trapping level is shallower. At the highest discharge rates the plume surfaces at port diameters of greater than six inches for the weaker density gradient condition.

Sensitivity to Effluent Temperature

Table 9 shows the sensitivity of diffuser performance to effluent temperature (an thus to effluent density). The results indicate that the initial dilution and trapping level are insensitive to small changes in effluent temperature (or density) for the range of port sizes under consideration at an effluent flow rate and depth similar to the expected conditions for the joint cannery outfall.

Sensitivity to Ambient Currents

All of the diffuser performance predictions presented above were based on a worst case scenario of zero ambient current. This is a conservative approach. Existing data (described in the Feasibility Study) indicates that a small current will be present nearly continuously at the diffuser site. Table 10 presents the diffuser performance predictions for currents at about the estimated 10 percentile level of 5 cm/sec (currents will be higher than this 90 percent of the time). Comparison of the results given in Table 10 to the zero current results of Table 8 demonstrates that, as expected, the presence of currents dramatically increases the initial dilution and trapping levels for the range of port sizes and effluent flows representative of the joint cannery outfall conditions.

SELECTION OF DIFFUSER CONFIGURATION

Based on the general guidelines for diffuser design, the results of the sensitivity analysis, and consideration of other design and site-specific factors, ports of 5-inch diameter were selected. During the time the sensitivity study was being conducted the exact location of the diffuser was selected and the depth at that location is 171 to 176 feet relative to mean lower low water.

The number of ports for the final diffuser configuration was based on the results of a series of model predictions for 5-inch ports as given in Table 11. Table 11 provides the predicted trapping

Table 8

EFFECT OF EFFLUENT FLOW RATE ON INITIAL DILUTION

Discharge Depth	= 160 ft.
Port Spacing	= 50 ft.
Effluent Temperature	= 85 F
Current Velocity	= 0 cm/sec

Results for Minimum Effluent Flow Rate = 1.5 mgd

PORT SIZE (inches)	PORT NUMBER	DENSITY PROFILE	DILUTION	TRAPPING LEVEL – ft (m)	PLUME WIDTH AT TRAP. LEVEL	PLUMES MERGE
4	7	S	540	75 (22.8)	43 (13.0)	YES
4	7	W	1068	15 (4.6)	61 (18.5)	YES
6	4	S	380	73 (22.2)	43 (13.2)	YES
6	4	W	743	13 (4.1)	62 (18.8)	YES

Results for Average Effluent Flow Rate = 2.0 mgd

PORT SIZE (inches)	PORT NUMBER	DENSITY PROFILE	DILUTION	TRAPPING LEVEL – ft (m)	PLUME WIDTH AT TRAP. LEVEL	PLUMES MERGE
4	7	S	471	73.8 (22.5)	44 (13.5)	YES
4	7	W	903	14.4 (4.4)	61 (18.5)	YES
6	4	S	334	71.9 (21.9)	46 (14)	YES
6	4	W	636	11.5 (3.5)	62 (19)	YES
8	2	S	291	47.9 (14.6)	57 (17.5)	YES
8	2	W	439	surface	64 (19.6)	YES

Results for Maximum Effluent Flow Rate = 3.8 mgd

PORT SIZE (inches)	PORT NUMBER	DENSITY PROFILE	DILUTION	TRAPPING LEVEL – ft (m)	PLUME WIDTH AT TRAP. LEVEL	PLUMES MERGE
4	7	S	357	73 (22.1)	49 (14.8)	YES
4	7	W	629	12 (3.6)	64 (19.6)	YES
6	4	S	256	69 (21.1)	50 (15.2)	YES
6	4	W	465	surface	67 (20.3)	YES

Note: S=strong density gradient W=weak density gradient

Table 9

EFFECT OF TEMPERATURE ON INITIAL DILUTION

Discharge Depth = 160 ft.
Effluent Flow Rate = 2.0 mgd
Port Spacing = 50 ft.

Results for Ambient Current = 0 cm/sec

PORT SIZE (inches)	PORT NUMBER	EFFLUENT TEMP. (F)	DENSITY PROFILE	DILUTION	TRAPPING LEVEL – ft (m)	PLUME WIDTH AT TRAP. LEVEL	PLUMES MERGE
4	7	85	S	468	74 (22.5)	44 (13.5)	YES
4	7	90	S	478	73 (22.4)	44 (13.4)	YES
4	7	85	W	900	14 (4.3)	62 (18.8)	YES
4	7	90	W	915	14 (4.4)	61 (18.7)	YES
6	4	85	S	332	72 (21.9)	43 (13.0)	YES
6	4	90	S	339	72 (21.8)	44 (13.5)	YES
6	4	85	W	630	11 (3.5)	62 (19.0)	YES
6	4	90	W	644	11 (3.3)	62 (19.0)	YES

Results for Ambient Current = 5.0 cm/sec (Currents higher than this 90% of time)

PORT SIZE (inches)	PORT NUMBER	EFFLUENT TEMP. (F)	DENSITY PROFILE	DILUTION	TRAPPING LEVEL – ft (m)	PLUME WIDTH AT TRAP. LEVEL	PLUMES MERGE
4	7	85	S	2507	78 (23.8)	69 (21)	YES
4	7	90	S	2511	78 (23.7)	69 (21)	YES
4	7	85	W	4651	19 (5.8)	108 (33)	YES
4	7	90	W	4659	19 (5.8)	112 (34)	YES
6	4	85	S	1471	77 (23.6)	82 (25)	YES
6	4	90	S	1472	77 (23.6)	82 (25)	YES
6	4	85	W	2725	18 (5.6)	128 (39)	YES
6	4	90	W	2730	18 (5.5)	131 (40)	YES

Note: S=strong density gradient W=weak density gradient

Table 10

EFFECT OF AMBIENT CURRENT AND EFFLUENT FLOW RATE
ON INITIAL DILUTION

Discharge Depth	= 160 ft.
Port Spacing	= 50 ft.
Effluent Temperature	= 85 F

PORT SIZE (inches)	PORT NUMBER	DENSITY PROFILE	DILUTION	TRAPPING LEVEL – ft (m)	PLUME WIDTH AT TRAP. LEVEL	PLUMES MERGE
Results for Minimum Effluent Flow Rate = 1.5 mgd						
Current Velocity = 5 cm/sec						
4	7	S	3244	78 (23.8)	66 (20)	YES
4	7	W	6079	19 (5.9)	102 (31)	YES
6	4	S	1902	77 (23.6)	79 (24)	YES
6	4	W	3552	18 (5.7)	200 (61)	YES
Results for Average Flow Rate = 2.0 mgd						
Current Velocity = 2.5 cm/sec						
4	7	S	1414	77 (23.6)	118 (36)	YES
4	7	W	2588	18 (5.5)	157 (48)	YES
6	4	S	854	76 (23.3)	85 (26)	YES
6	4	W	1557	17 (5.1)	125 (38)	YES
8	2	S	487	73 (22.4)	79 (24)	YES
8	2	W	866	14 (4.2)	131 (40)	YES
Current Velocity = 5.0 cm/sec						
4	7	S	2509	78 (23.8)	69 (21)	YES
4	7	W	1472	77 (23.6)	82 (25)	YES
6	4	S	4655	19 (5.8)	110 (34)	YES
6	4	W	2728	18 (5.6)	129 (40)	YES
Results for Maximum Flow Rate = 3.8 mgd						
Current Velocity = 5 cm/sec						
4	7	S	1440	77 (23.6)	72 (22)	YES
4	7	W	2600	18 (5.6)	121 (37)	YES
6	4	S	857	76 (23.3)	85 (26)	YES
6	4	W	1536	17 (5.2)	144 (44)	YES

Note: S=strong density gradient W=weak density gradient

level, initial dilution, and Froude Number for a range of effluent flow rates and for both density gradient conditions described above. Effluent density was based on 40 percent sea water and a temperature of 87.5 degrees F. The results of these model predictions lead to the selection of a diffuser with the following characteristics:

- Number of Ports: 6 ports total
  4 ports active (open)
  2 ports closed (for future use)
- Port Spacing: 50 feet between ports
  Alternating sides
- Port Size: 5.065 inches (ID)
- Port Orientation: 90 degrees to centerline of pipe
  15 degrees to horizontal (upward)

The number of ports to be built is larger than the number of ports to be used. This provides flexibility for growth and a safety factor in the event of port clogging. This approach was taken because of the depth of water and difficulty of modifying and maintaining the diffuser once in place.

PREDICTED DIFFUSER PERFORMANCE

After determining the final diffuser configuration described above and the location (depth) of the diffuser an additional set of model simulations was conducted to predict final diffuser configuration performance. The results of these predictions are given in Table 12 and detailed input and output from UDKHDEN are provided in the Appendix A to this memorandum. For the final configuration model predictions the following conditions were used:

- Effluent Discharge Rates: 1.41, 2.39, and 3.40
- Effluent Temperature: 85 degrees F
- Effluent Salinity: Calculated for 0.6 mgd of sea water (the balance freshwater)
- Ambient Conditions: Density as described above and zero current speed

Table 11
SELECTION OF NUMBER OF 5-inch PORTS FOR DIFFUSER

DENSITY GRADIENT S=strong W=weak	EFFLUENT FLOW (mgd)	NUMBER OF 5-inch PORTS	TRAPPING LEVEL (m below surface)	INITIAL DILUTION	FROUDE NUMBER
S	1.5	2	22	350	4.4
		4	23	491	5.8
		6	23	611	8.7
		8	23	707	17.5
	2.0	2	22	310	23.2
		4	23	428	11.6
		6	23	524	7.7
		8	23	608	5.8
	3.8	2	22	237	44.6
		4	22	312	22.3
		6	23	378	14.9
		8	23	433	11.2
W	1.5	2	4	565	17.8
		4	4	832	8.9
		6	5	1053	6.0
		8	5	1248	4.5
	2.0	2	3	487	23.6
		4	4	707	11.81
		6	4	896	7.87
		8	5	1059	5.91
	3.8	2	0	367	45.5
		4	3	498	22.8
		6	4	616	15.2
		8	4	721	11.4

Table 12
PREDICTED PERFORMANCE OF FINAL DIFFUSER CONFIGURATION

DENSITY GRADIENT	EFFLUENT FLOW (mgd)	TRAPPING LEVEL (m below surface)	INITIAL DILUTION
Stronger Gradient	1.41	23	467
	2.39	22	393
	3.40	21	346
Weaker Gradient	1.41	4	817
	2.39	3	659
	3.40	-	586

The model predictions indicate that dilutions are expected to be over 300:1 under all conditions and are over 400:1 under most conditions.

AMBIENT CONCENTRATIONS (OUTSIDE ZONE OF MIXING)

Ambient concentrations for a range of nutrient loadings and discharge locations were developed and presented in the Feasibility Study and Appendices to the Feasibility Study. These predictions were done using a wastefield transport model (PT121) developed for Pago Pago Harbor. The model is described in the Feasibility Study. Additional runs with the model were made for the final diffuser location.

Table 13 presents the results of the PT121 model runs for the final diffuser site. The loadings listed in Table 13 are input to the model as constants and can be interpreted to represent the maximum loading or the long term average loading. The interpretation of the results depends on the interpretation of the input loading conditions. The primary results of the site-specific model predictions are:

- **Interpretation of the model input as the maximum loading is the most conservative approach.** In this case the model predicts the resulting concentrations throughout the harbor that would occur if the maximum loadings were continuous (that is maximum and average were the same).

Since the loadings vary considerably (see Tables 2 and 3 and Figures in Appendix B of this memorandum), the predicted concentrations based on maximum loadings are values that are higher than would ever occur. The combined average loading of TP is only 49 percent of the combined maximum loading. For TN the combined average is only 50 percent of the combined maximum. The use of the maximum as an average is extremely conservative.

- **Interpretation of the model input loadings as averages means that the predicted concentrations in the harbor are representative of long term averages.** The actual concentrations in the harbor would fluctuate about these averages. Because of the slow response time of the harbor and the rapid variations of the loadings the actual concentrations in the harbor would not vary as much as the loadings. Concentrations in the harbor would never reach a value near that predicted for maximum loadings input as constant. For example, if the combined average TN loading is 1500 pounds per day and the maximum value is 4000 pounds per day then, based on the results given in Table 13, the average concentration in the harbor (highest value outside the mixing zone) is predicted to be higher than 0.165 mg/l and will always be lower than 0.243 mg/l.

- **Present combined average loadings are approximately 1500 lbs/day (1567 lbs/day for the samples taken during the period of record described above). This loading will result in a predicted maximum TN concentration outside of the zone of mixing of 0.165 mg/l.** This is comfortably below the water quality standard. For TP the loading is about 300 lbs/day (294 lbs/day for the period of record). This loading results in a maximum TP concentration, outside the zone of mixing, of about 0.022 mg/l.

- **The model predictions indicate that, outside the zone of mixing, the TN standard of 0.200 mg/l will be met at a constant loading of 2600 lbs/day and that the TP standard of 0.030 mg/l will be met at a constant loading of 570 lbs/day.** The 2600 lbs/day TN level includes 95 to 99+ percent of the data since the implementation of high strength waste segregation. The 570 lbs/day TP level includes virtually all the data since the implementation of high strength waste segregation.

Table 13
MODEL PREDICTIONS OF MAXIMUM CONCENTRATIONS
OUTSIDE THE ZONE OF MIXING AT THE FINAL DIFFUSER SITE
FOR A RANGE OF TN AND TP LOADINGS

TN LOADING (lbs/day)	MAXIMUM TN CONCENTRATION (mg/l)		TP LOADING (lbs/day)	MAXIMUM TP CONCENTRATION (mg/l)
1500	0.165		300	0.022
2000	0.180		400	0.025
2500	0.197		500	0.028
3000	0.212		600	0.031
3500	0.231		700	0.034
4000	0.243		800	0.038

Examination of the data for concentrations, loadings, and effluent flow rates, since high strength waste segregation, indicates that there is no significant trend of loading with production. Plots of concentration and loading as a function of relative production (percent of maximum in the period of record) are given in Appendix B. The time series of loadings for each cannery, since the implementation of high strength waste segregation, are also given in Appendix B and indicate that there is no strong correlation between canneries and that the fluctuations are of relatively short period. The variations in loading can be considered as a random record of short period fluctuations about a mean in the evaluation of impacts on harbor nutrient concentrations. ?

recovery time ?

Based on the above observations the model was used to evaluate the increase in TN and TP concentrations that would occur for increases in loadings above a range of values for the combined long term average. The results of this analysis are given in Table 14. The table presents the number of days required to increase maximum TN and TP concentrations to the standard (outside of the zone of mixing). For example, if the average TN loading is 1500 lbs/day then an increased TN loading of 3000 lbs/day would have to exist for 7 consecutive days to increase the concentration of TN to 0.200 mg/l. This 0.200 mg/l concentration would be the highest concentration outside the zone of mixing; concentrations throughout the rest of the harbor would be lower than 0.200 mg/l.

The loadings used in the model simulation are based on data taken only during product processing operations and result in artificially high average loading values. These results in an extra degree of conservatism in an already conservative approach. All the model assumptions and applications tend to predict higher concentrations than would be the case with more realistic assumptions.

Table 14
MODEL PREDICTIONS OF MAXIMUM CONCENTRATIONS
FOR TN AND TP LOADINGS ELEVATED ABOVE AVERAGE

AVERAGE TN LOADING (lbs/day)	ELEVATED LOADING (lbs/day)				AVERAGE TP LOADING (lbs/day)	ELEVATED LOADING (lbs/day)		
	3000	3500	4000			600	700	800
	NUMBER OF DAYS BEFORE EXCEEDING 0.200 mg/l					NUMBER OF DAYS BEFORE EXCEEDING 0.030 mg/l		
1500	10	7	4		300	12	6	4
2000	7	4	3		400	9	4	3
2500	0	0	0		500	4	2	1

Examination of the available data indicates that TN loadings exceeding the average (1500 lbs/day) are not predicted to result in concentrations exceeding 0.200 mg/l. The average and maximum effluent TN and TP concentrations can increase above present values, to account for future growth, and still meet water quality standards. Table 14 indicates the average and maximum loadings predicted to result in compliance outside the zone of mixing.

by how much?

REQUIRED ZONE OF MIXING SIZE

The wastefield transport model described in the preceding section of this memorandum provides an assessment of the average concentrations throughout the harbor over time scales greater than a tidal period and space scales consistent with the cell size (200 meters horizontal dimension). The initial dilution model described above provides an assessment of the mixing action of the effluent plume with the receiving water. Neither of these models provides precise details on the geometry of a zone of mixing. For the purposes of the discussion in this section, the defined a zone of mixing is that area outside of which the water quality standards are achieved.

The enclosed nature of the ~~harbor~~ random and concomitant long flushing and residence times, the stochastic nature of the predominantly wind-driven circulation, and the restrictive water quality standards all combine to make the precise definition of a zone of mixing a somewhat subjective process. However, the results of the wastefield transport model predictions show compliance with the water quality standards at specified loadings on a long-term average basis.

A number of approaches can be used to describe the appropriate zone of mixing dimensions. These approaches vary in their spatial and temporal resolution as well as in the physical approach used. The approaches can be broadly classified as initial dilution based, volumetric based, or based on analysis of subsequent (far-field) dilution. Each of these approaches is discussed below.

ZONE OF MIXING BASED ON INITIAL DILUTION

If a zone of mixing is to be based on initial dilution only, the receiving water must have a sufficiently low concentration of the constituent of concern that the concentration of the plume, at the end of the initial dilution process, meets the water quality standards. In an enclosed system like Pago Pago Harbor, the receiving water concentration (steady state or long term average) is elevated above the open ocean background concentration. Background concentration is used here to indicate the concentration that would be found if there were no release of the constituent. The steady-state concentration refers to the concentration in any particular area of the harbor that results from the long-term release of the constituent.

The required initial dilution (S) to meet a particular water quality standard concentration at the end of the initial dilution process (Cs) depends on the effluent concentration (Ce) and the ambient (steady state) concentration (Ca). The relationship between these variables is:

$$S\ (C_a - C_s) = (\cancel{C_s}\ C_a{}^{*} - C_e).$$

Thus, the standard can never be met if the ambient concentration equals the water quality standard and only initial dilution is accounted for in the zone of mixing definition.

The closer the values of the standard and the ambient concentrations, the more difficult it is to meet the standards, that is, the higher the initial dilution must be to meet the water quality

* As per Steve Costa's memo of 11/10/91

standard. For example, if the ambient TN concentration is the ocean background (the outfall is beyond the harbor entrance) of 0.12 mg/l and the water quality standard is 0.200 mg/l, the required initial dilution to meet the standard, except within the effluent plume, is expressed as:

$$S = (Ce - \cancel{0.200}\ 0.120^{*})/0.080$$

Typical post-segregation median effluent concentrations for the combined cannery discharges are expected to be approximately 70 to 100 mg/l. This means that initial dilutions on the order of 875 to 1,250 are required, which are probably much higher than can practically be obtained. With the discharge in the harbor where the ambient concentrations are higher results in even higher, and unattainable, initial dilution requirements. A zone of mixing based solely on initial dilution is not feasible for the present water quality standards.

ZONE OF MIXING BASED ON VOLUMETRIC ANALYSIS

The transport model used to predict ambient conditions provides an assessment of the size of the zone of mixing, based on a description of long-term average concentrations. The resolution of the model is a cell 200 meters square (656 feet square). In addition, the model is a depth-averaged, completely stirred model. The fine-scale details of the effluent plume and the nearfield concentrations are neither square nor constant with depth or the horizontal dimension of a model cell. However, the model does give a good indication of the strength of the concentration gradient that can exist for the dispersion coefficient applicable for the model cell size.

The model was run with discharge to two cells. The resulting ambient concentrations given in Table 13 are the maximum predicted outside of those two cells. The time required to exceed the standard as given in Table 14 also is for areas outside of the two cells where effluent is discharged. For the discharge location the depth of the diffuser is about 175 feet and the minimum initial dilution expected from the initial dilution modeling is over 350:1. For an effluent concentration of TN of 100 mg/l, the concentration at the end of the initial dilution process is about 0.49 mg/l, based on an ambient concentration of 0.200 mg/l. The volume of water in 2 model cells is over 150 times that involved in the initial dilution process, and the concentration after initial dilution is approximately 2 to 3 times the average predicted for the 2 model cells.

The overall volumetric requirements for a zone of mixing predicted by the wastefield transport model appear reasonable (there is suf-

* As per S. Costa's memo of 11/10/91

ficient volume of water). However, the detailed geometry and spatial variability of the area where water quality standards are exceeded is not well addressed by the wastefield transport model (which predicts average long term conditions).

The wastefield transport model used in this study does provide a useful estimate of the subsequent dilution except close to the discharge point. The wastefield transport model (PT121) was found to predict observed concentrations at stations near (within 1000 feet of) the existing discharge. Thus, the results of the model near the point source discharge appear to be acceptable at a distance of about 1,000 feet or possibly less. The analysis of the wastefield transport model predictions presented in the previous section of this memorandum was based on providing a zone where water quality standards might be exceeded that was always less than 300 feet from the model discharge point.

If, as a conservative approach, the cells within which effluent is released and all the surrounding cells are taken as a zone of mixing the size of the zone of mixing would be 800 by 600 meters (approximately 2600 by 2000 feet) aligned in the direction of the diffuser.

APPLICATION OF THE FARFIELD DILUTION MODEL

The wastefield transport model described above is a depth-averaged model that cannot account for the fact that, near the discharge point, the wastefield will exhibit a gradient in concentration with depth and might be contained in a distinct layer of the water column. To investigate the expected concentrations near the discharge point the subsequent dilution model CDIFF was used.

The subsequent dilution model (CDIFF) was used and is described in more detail in the Feasibility Study and associated references. This model has features that make it conservative; that is, it provides predictions of dilutions that are probably low (high concentrations). These features include the following:

- The model allows no diffusion in the direction of the current. This results in particularly wide wastefields at low current speeds and physically unrealistic results at very low current speeds. This aspect of the model had to be considered for this application and was addressed as described below.

- The model allows no mixing in the vertical direction and assumes a constant "layer thickness". This results in an overestimate of concentrations.

- The model, as supplied by EPA, has set values for calculating diffusion coefficients as a function of plume dimension. These values result in a diffusion coefficient, at the start of subsequent dilution, that is about the same as that derived from dye experiments in Pago Pago Harbor. Those experiments were based on visual (photographic) observation rather than concentration measurements. This leads to an underestimate of the eddy diffusion coefficient and means CDIFF is underestimating the dilution factor (overestimating concentration) at least near the beginning of the subsequent dilution process.

- At the end of initial dilution, the concentration of the plume is appropriately described by adding or superimposing it on the ambient concentration. At the end of the subsequent dilution process, the concentration of the plume is the ambient concentration. However, the calculation of subsequent dilution is usually carried out by superimposing the plume concentration on the ambient concentration throughout the entire area considered. This gives conservative (concentration predicted too high) results that are more conservative as the distance from the source increases.

As mentioned above CDIFF does not work well under near-zero current conditions. The model allows only advective transport in the longitudinal direction (direction of current) and only diffusive transport in the lateral direction. Thus, for near zero current speeds no dispersion is allowed in the longitudinal direction and the model results are physically unrealistic, and are not usable for predictions. To be physically realistic, the longitudinal (advective) transport term should be at least as large as the lateral (diffusive) transport term. In order to meet this condition and keep model predictions physically realistic the model should not be applied for currents less than about 0.05 cm/sec. This current speed is based on an analysis done for the application of the model to Pago Pago Harbor.

For a current speed of 0.05 cm/sec and for diffusivity proportional to the length scale of the plume (which is typical for enclosed bodies of water), the model simulates the zero-current-speed situation. Under the stated current speed and diffusivity conditions the model predicts diffusive and advective fluxes of about the same size near the origin. This is equivalent to setting the strength of diffusive transport the same in both directions, which is a physically realistic approach for the space and time scales under consideration in this case.

The model output for CDIFF provides a description of subsequent dilution as a function of distance from the plume location at the end of initial dilution. The output from CDIFF is included as Appendix C. For the Feasibility Study the subsequent dilution was applied to the predicted gradient of ambient concentrations. For the analysis below the ambient concentrations are held constant, which is a somewhat more conservative approach. Tables 15A through 15D summarize the calculations and approach to predicting the required mixing zone dimensions.

Tables 15A-D summarize two approaches, which are similar to the approaches described above for the wastefield transport model:

- The first approach assumes a continuous loading for a range of values corresponding to a range of frequency of occurrences. This approach can be thought of as predicting the median (50 percentile) conditions for existing and increased (over 50% percentile) median loadings and concentrations.

- The second approach assumes a peak loading occurs superimposed on ambient conditions representative of the present median condition. An estimate of the number of days of elevated loadings that would have to occur before water quality standards were violated at the edge of the mixing zone was provided above in the discussion of the ambient concentrations predicted by the wastefield transport model.

There is no clear relationship between loading, concentration, and effluent discharge rate. The values used in the calculations were all selected corresponding to the same frequency of occurrence level. If the variables were well correlated this frequency would correspond to the expected frequency of occurrence of the result (i.e. required zone of mixing size). If the variables were not correlated at all then the frequency of the result could be much lower than the frequency of each variable. Since the relationship between the variables is weak, the result is conservative (predicted requirement for zone of mixing dimension is too large).

Tables 15A-D provide estimates of mixing zone size for TP and TN and for stronger and weaker density gradients. The tables are constructed as follows:

- Effluent flows, nutrient concentrations, and nutrient loadings are tabulated based on a set of frequencies from Tables 1 through 3 above.

Table 15A
REQUIRED DIAMETER FOR ZONE OF MIXING
TN - STRONGER STRATIFICATION

	CONTINUOUS CONDITIONS				PEAK SUPERIMPOSED ON MEDIAN			
FREQUENCY (Percent of Time Less Than or Equal to)	50%	75%	90%	95%	75%	90%	95%	100%
FLOW (mgd)								
SKS	1.83	1.95	2.00	2.10	1.95	2.00	2.10	2.61
SPC	0.56	0.64	0.71	0.76	0.64	0.71	0.76	0.79
COMBINED	2.39	2.59	2.71	2.86	2.59	2.71	2.86	3.40
CONCENTRATION (mg/l)								
SKS	66.00	79.00	90.00	114.00	79.00	90.00	114.00	125.00
SPC	104.00	121.00	140.00	146.00	121.00	140.00	146.00	183.00
COMBINED	74.90	89.38	103.10	122.50	89.38	103.10	122.50	138.48
LOADING (lbs/day, calc)								
SKS	1008	1286	1502	1998	1286	1502	1998	2723
SPC	486	646	830	926	646	830	926	1206
COMBINED	1494	1932	2332	2924	1932	2332	2924	3929
LOADING (lbs/day, data)								
SKS	1020	1228	1427	1720	1228	1427	1720	1925
SPC	477	570	673	772	570	673	772	1052
COMBINED	1497	1798	2100	2492	1798	2100	2492	2977
AMBIENT CONC. (mg/l)	0.165	0.174	0.183	0.197	0.165	0.165	0.165	0.165
STANDARD (mg/l)	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200
REQUIRED DILUTION								
TOTAL DILUTION	~~2134~~	3430	6053	40768	2548	2940	3494	3951
INITIAL DILUTION	~~395~~	380	375	370	380	375	370	345
SUBSEQUENT DILUTION	5.4	9.0	16.1	110.2	6.7	7.8	9.4	11.5
REQUIRED DIAMETER OF ZONE OF MIXING (feet)	280	480	940	-----	340	400	500	660

Table 15B
REQUIRED DIAMETER FOR ZONE OF MIXING
TN - WEAKER STRATIFICATION

	CONTINUOUS CONDITIONS				PEAK SUPERIMPOSED ON MEDIAN			
FREQUENCY (Percent of Time Less Than or Equal to)	50%	75%	90%	95%	75%	90%	95%	100%
FLOW (mgd)								
SKS	1.83	1.95	2.00	2.10	1.95	2.00	2.10	2.61
SPC	0.56	0.64	0.71	0.76	0.64	0.71	0.76	0.79
COMBINED	2.39	2.59	2.71	2.86	2.59	2.71	2.86	3.40
CONCENTRATION (mg/l)								
SKS	66.00	79.00	90.00	114.00	79.00	90.00	114.00	125.00
SPC	104.00	121.00	140.00	146.00	121.00	140.00	146.00	183.00
COMBINED	74.90	89.38	103.10	122.50	89.38	103.10	122.50	138.48
LOADING (lbs/day, calc)								
SKS	1008	1286	1502	1998	1286	1502	1998	2723
SPC	486	646	830	926	646	830	926	1206
COMBINED	1494	1932	2332	2924	1932	2332	2924	3929
LOADING (lbs/day, data)								
SKS	1020	1228	1427	1720	1228	1427	1720	1925
SPC	477	570	673	772	570	673	772	1052
COMBINED	1497	1798	2100	2492	1798	2100	2492	2977
AMBIENT CONC. (mg/l)	0.165	0.174	0.183	0.197	0.165	0.165	0.165	0.165
STANDARD (mg/l)	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200
REQUIRED DILUTION								
TOTAL DILUTION	2134	3430	6053	40768	2548	2940	3494	3951
INITIAL DILUTION	660	640	630	620	640	630	620	585
SUBSEQUENT DILUTION	3.2	5.4	9.6	65.8	4.0	4.7	5.6	6.8
REQUIRED DIAMETER OF ZONE OF MIXING (feet)	160	280	520	----	200	220	280	340

Table 15C
REQUIRED DIAMETER FOR ZONE OF MIXING
TP - STRONGER STRATIFICATION

	CONTINUOUS CONDITIONS				PEAK SUPERIMPOSED ON MEDIAN			
FREQUENCY (Percent of Time Less Than or Equal to)	50%	75%	90%	95%	75%	90%	95%	100%
FLOW (mgd)								
SKS	1.83	1.95	2.00	2.10	1.95	2.00	2.10	2.61
SPC	0.56	0.64	0.71	0.76	0.64	0.71	0.76	0.79
COMBINED	2.39	2.59	2.71	2.86	2.59	2.71	2.86	3.40
CONCENTRATION (mg/l)								
SKS	8.00	11.00	14.00	16.00	11.00	14.00	16.00	20.00
SPC	34.00	38.00	42.00	43.00	38.00	42.00	43.00	48.00
COMBINED	14.09	17.67	21.34	23.17	17.67	21.34	23.17	26.51
LOADING (lbs/day, calc)								
SKS	122	179	234	280	179	234	280	436
SPC	159	203	249	273	203	249	273	316
COMBINED	281	382	483	553	382	483	553	752
LOADING (lbs/day, data)								
SKS	127	171	230	257	171	230	257	312
SPC	153	188	208	225	188	208	225	267
COMBINED	280	359	438	482	359	438	482	579
AMBIENT CONC. (mg/l)	0.021	0.024	0.026	0.027	0.021	0.021	0.021	0.021
STANDARD (mg/l)	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030
REQUIRED DILUTION								
TOTAL DILUTION	1562	2940	5326	7715	1960	2367	2572	2942
INITIAL DILUTION	395	380	375	370	380	375	370	345
SUBSEQUENT DILUTION	4.0	7.7	14.2	20.9	5.2	6.3	7.0	8.5
REQUIRED DIAMETER OF ZONE OF MIXING (feet)	200	400	800	1300	260	320	360	460

Table 15D
REQUIRED DIAMETER FOR ZONE OF MIXING
TP - WEAKER STRATIFICATION

	CONTINUOUS CONDITIONS				PEAK SUPERIMPOSED ON MEDIAN			
FREQUENCY (Percent of Time Less Than or Equal to)	50%	75%	90%	95%	75%	90%	95%	100%
FLOW (mgd)								
SKS	1.83	1.95	2.00	2.10	1.95	2.00	2.10	2.61
SPC	0.56	0.64	0.71	0.76	0.64	0.71	0.76	0.79
COMBINED	2.39	2.59	2.71	2.86	2.59	2.71	2.86	3.40
CONCENTRATION (mg/l)								
SKS	8.00	11.00	14.00	16.00	11.00	14.00	16.00	20.00
SPC	34.00	38.00	42.00	43.00	38.00	42.00	43.00	48.00
COMBINED	14.09	17.67	21.34	23.17	17.67	21.34	23.17	26.51
LOADING (lbs/day, calc)								
SKS	122	179	234	280	179	234	280	436
SPC	159	203	249	273	203	249	273	316
COMBINED	281	382	483	553	382	483	553	752
LOADING (lbs/day, data)								
SKS	127	171	230	257	171	230	257	312
SPC	153	188	208	225	188	208	225	267
COMBINED	280	359	438	482	359	438	482	579
AMBIENT CONC. (mg/l)	0.021	0.024	0.026	0.027	0.021	0.021	0.021	0.021
STANDARD (mg/l)	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030
REQUIRED DILUTION								
TOTAL DILUTION	1562	2940	5326	7715	1960	2367	2572	2942
INITIAL DILUTION	660	640	630	620	640	630	620	585
SUBSEQUENT DILUTION	2.4	4.6	8.5	12.4	3.1	3.8	4.1	5.0
REQUIRED DIAMETER OF ZONE OF MIXING (feet)	120	220	460	700	160	180	200	240

- Loadings are also calculated based on flows and concentrations (indicated as "calc"). The results of this calculation are loadings higher than observed indicating a weak, and possibly negative, correlation between flow and concentration. The previously tabulated loadings (indicated as "data") are used in the following calculations of the zone of mixing size. This approach corresponds to an assumption of a strong positive correlation between flow rate and concentration which is an extremely conservative (worst case) approach.

- Ambient concentrations are based on the predictions of the wastefield transport model for the area adjacent to (but not including) the cells representing the immediate point source (Table 13).

- The required dilution is calculated based on effluent, ambient, and the desired final (water quality standard) concentrations using the same relationship given above for zone of mixing based on initial dilution.

- Initial dilutions correspond to flows as given in Table 12.

- Required distances for the mixing zone are based on the required subsequent dilution to meet the water quality standard and the relationship between distance and subsequent dilution. Subsequent dilution as a function of distance is in the output from CDIFF given in Appendix C.

During times of stronger density gradients a zone of mixing allowing a 1300 foot travel distance for the plume would provide for the worst case condition and allow for future expansion. Mean loadings could increase by about 70 percent and still be accommodated by this zone of mixing. During times of stronger density gradients the plume would remain trapped well below the surface (see Table 12 and Appendix A). Even if the plume moved toward shore it would remain submerged and not impact the coral reef.

During times of weaker density gradients the travel distance of the plume is much less than for stronger gradient conditions. This is because the initial dilution will be higher. Based on the analysis summarized in Tables 15B and 15D it appears that during times of plume surfacing the water quality standards will be met before the plume can reach the reef area.

RESULTS OF ZONE OF MIXING ANALYSIS

A conservative estimate of zone of mixing size, based on the above models and analyses, is as follows:

- For present loading levels, and for average long-term conditions, a zone of mixing of a size corresponding to two model cells appears reasonable. However, a larger size is prudent to account for known variability and projected future expansion.
- For maximum loading values, a zone of mixing of 1,300 feet in radius (centered on the outfall diffuser) appears sufficient and provides a reasonable factor of safety and allows for future increases in median loading values.

The zone of mixing is defined above such that at any given time the concentration within the zone would be above the water quality standard at the boundary of the zone over less than 1/4 of the area of the zone. Within most of such a designated zone of mixing, at any given time, the water quality standards would be met. Thus the actual size, at any time, of the area where water quality standards would not be met (an "effective" zone of mixing) is very small and would involve a fraction of one percent of the volume of the harbor. However, because the currents are always changing direction and speed, this "effective" zone of mixing is constantly moving within the borders of the overall zone of mixing. The developments presented above, on which the size of the zone of mixing was based, were constructed to be a worst case scenario. Conservative assumptions were used throughout the application of models, analysis, and data interpretation.